CAD Run 13 Report

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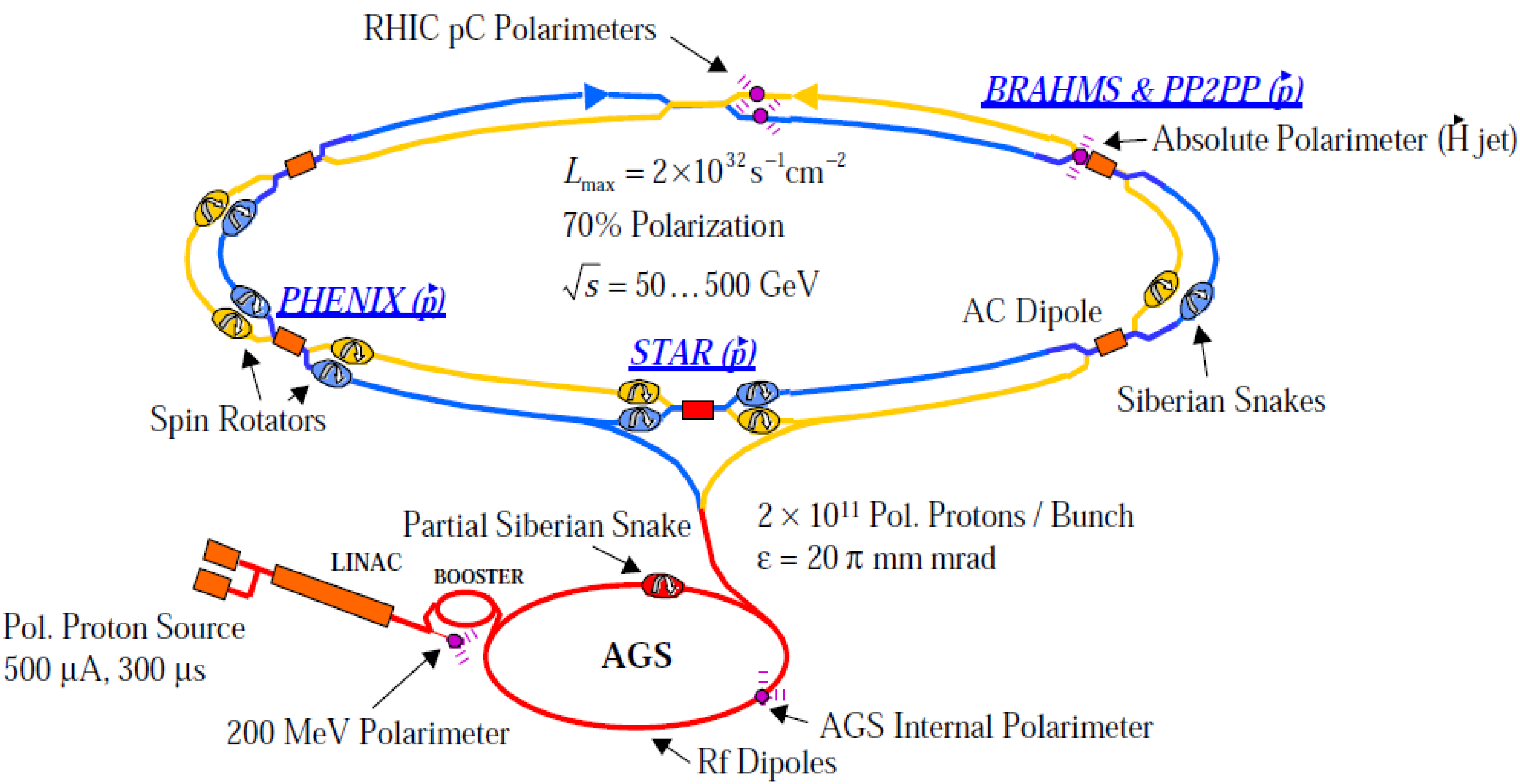
Polarization is Magic Run Report!

AGS-RHIC COMPLEX



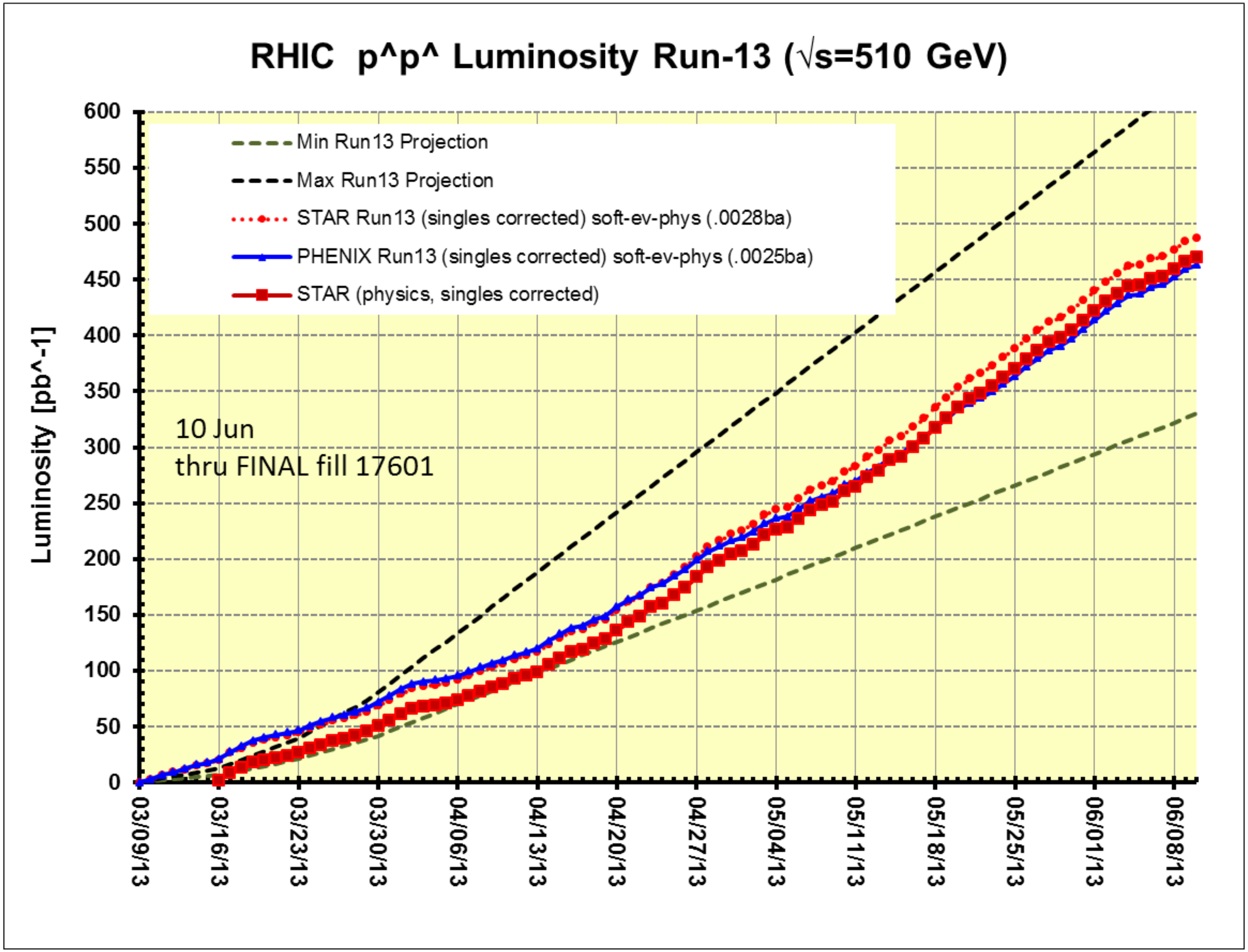
Highlights of Run

- Achieved new records in peak luminosity, total store luminosity.
  - Peak : 238×10^{30} cm^{-2} s^{-1}
  - Avg. 10 best Stores: 132×10^{30} cm^{-2} s^{-1}
- Several important milestones achieved:
  - Unprecedented control of longitudinal emittance: bunch-bunch damper (dropped by ~ 3ns at Collision)
  - Commissioning of new high current source
  - Testing e-lens lattice and e-lens systems

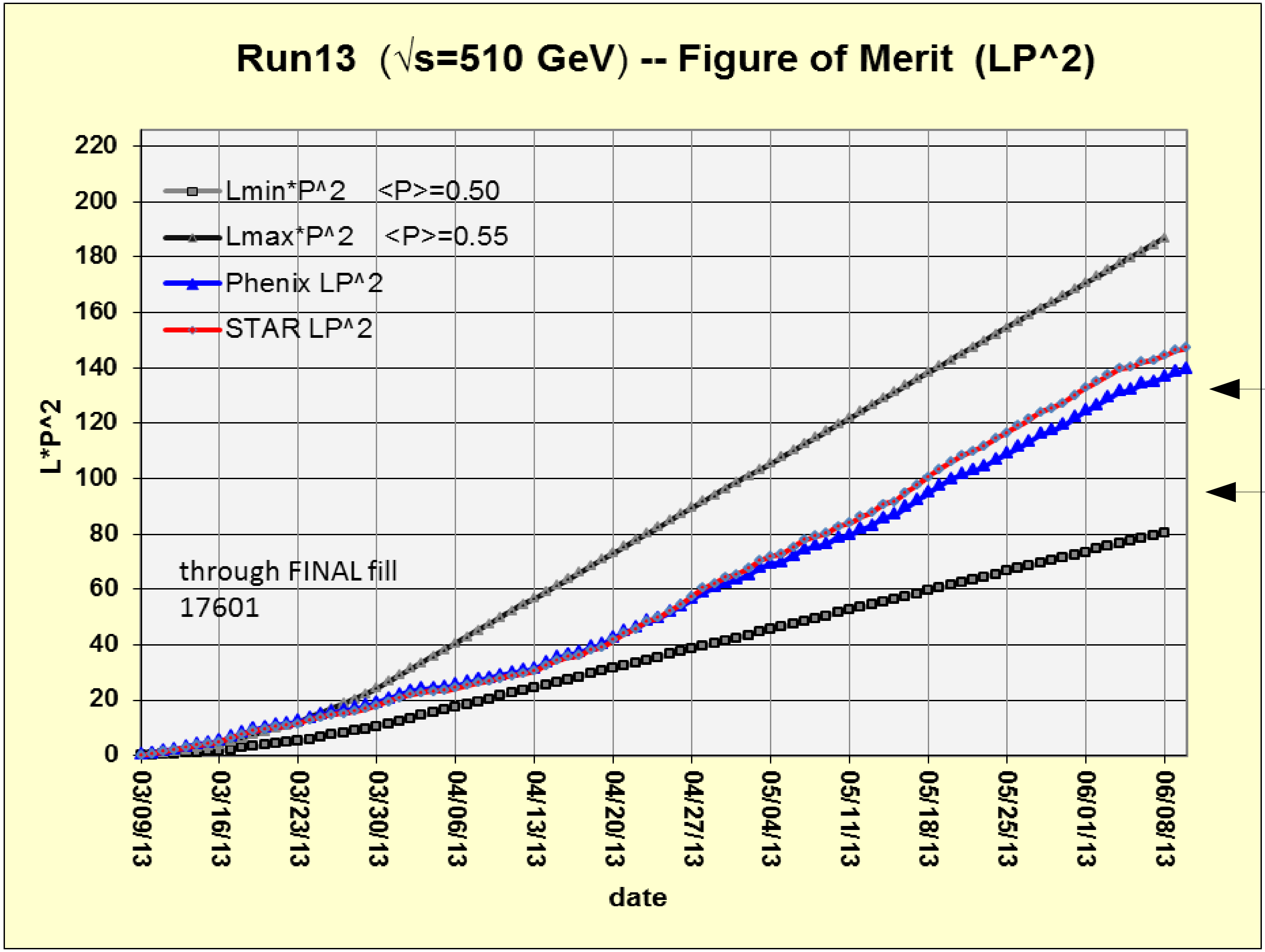
Preliminary, with Run 13 cross sections, PHENIX and STAR ***log based singles correction***

STAR Goal, 165 pb^{-1} recorded, 275 pb^{-1} delivered, ≥ 55% polarization

PHENIX Revised Goal, 150 pb^{-1} recorded, 450 pb^{-1} delivered, ≥ 55% polarization



Preliminary, with Run 13 cross sections, PHENIX and STAR ***log based singles correction*** ***These are initial estimates we know real value will be larger***



136.12 PHENIX GOAL LP^2

83.19 STAR Goal LP^2

Using average polarizations from CNI polarization from http://www.phy.bnl.gov/cnipol/fills/

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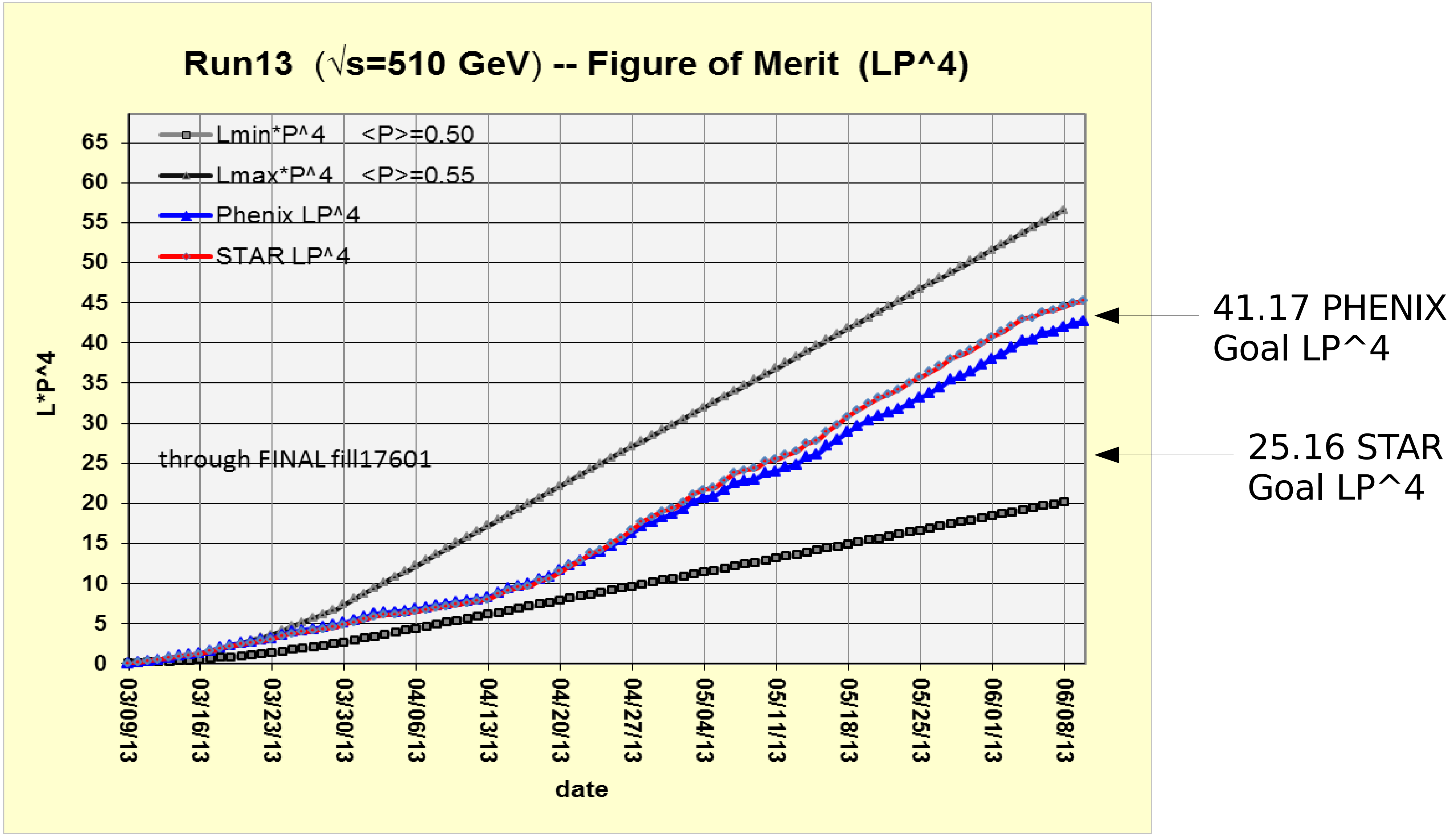

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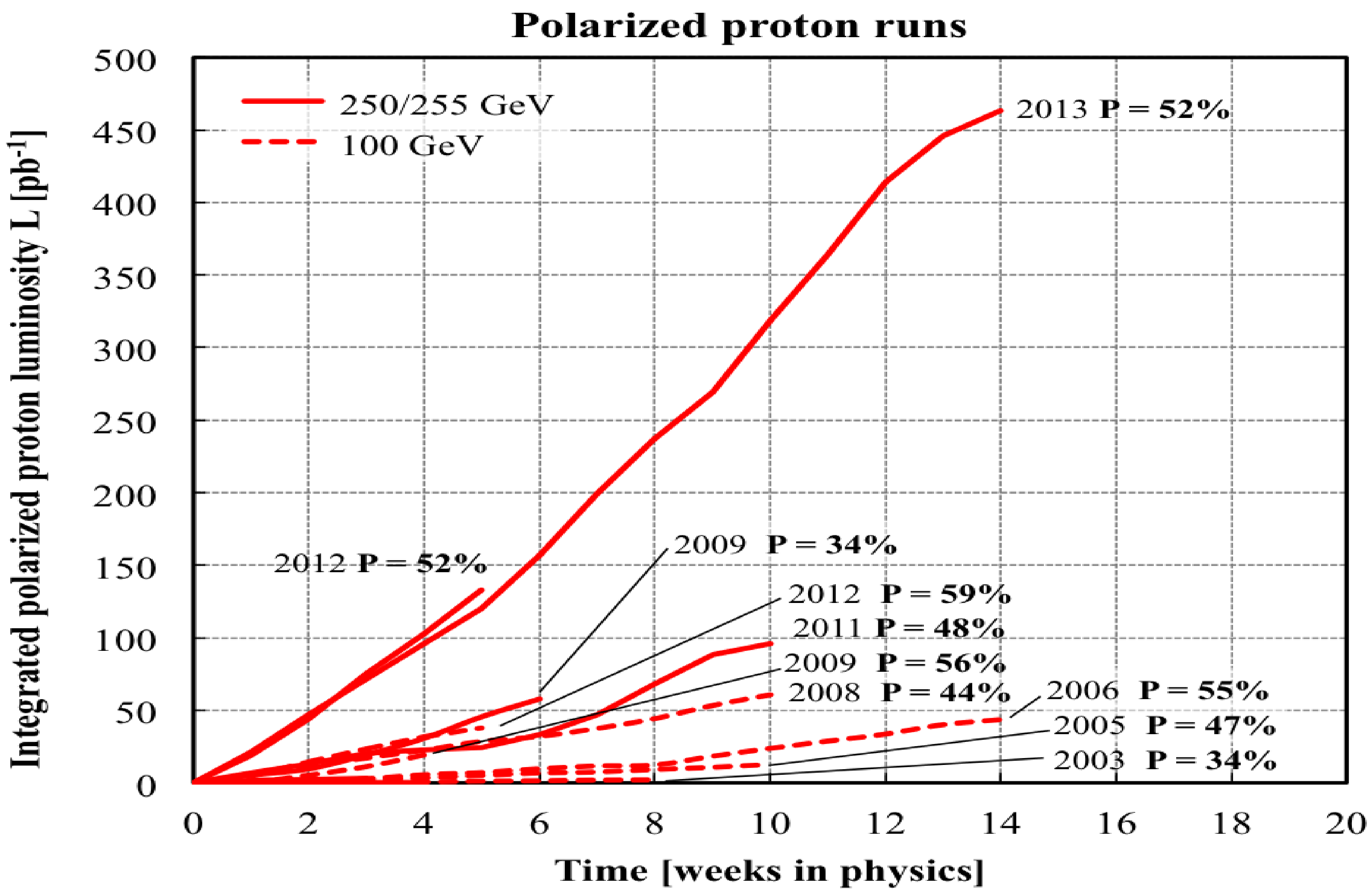
Compared to previous Runs

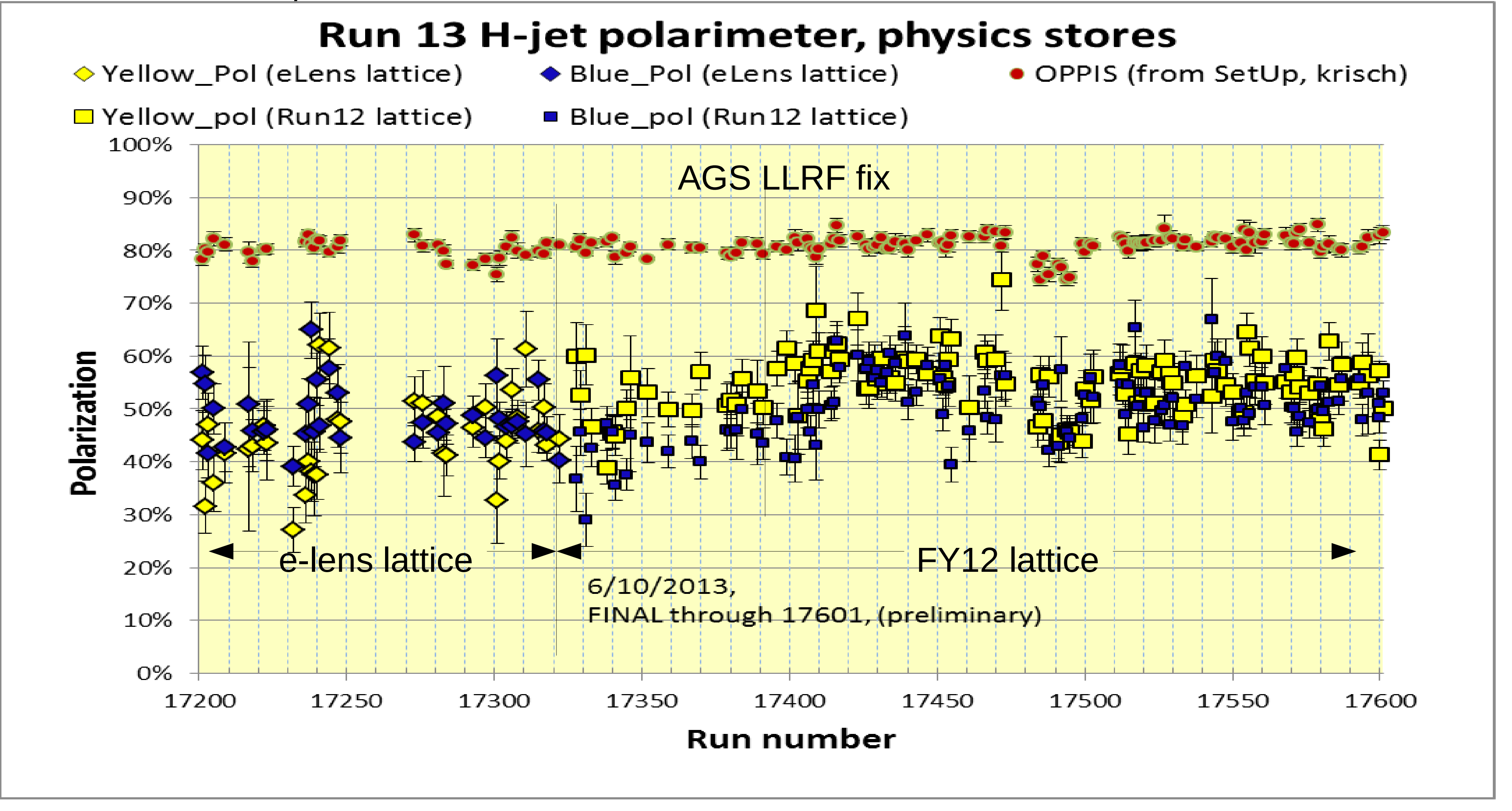


Courtesy W. Fischer

Yellow average = 44.3 ± 0.8%
Blue average = 47.7 ± 0.7%
Average = 46.0%
stores 17201-17322 (eLens lattice)

Yellow average = 55.1± 0.4%
Blue average = 51.8 ± 0.3%
Average = 53.4%
stores 17396 – 17601 (Run 12 lattice after LLRF fix)

Average for all fills: Blue = 50.1% +/- 0.3%, Yellow = 53.0% +/- 0.3%



https://wiki.bnl.gov/rhicspin/Polarimetry/H-jet/Run13

RF Upgrades

- Low Level RF systems in AGS
  - Replace 20 year old system -many parts no longer supported
  - Uniform hardware across accelerator systems
  - Improved ATR synchro
- Longitudinal bunch-by-bunch damper:
  - Raised the effective limit of intensity we could take up the RHIC energy ramp. The bunch-by-bunch damper controlled the bunch length and alleviated the squeeze-out losses on the ramp. This is when the rate of change of Dipole Field reaches a maximum and the accelerating RF phase space acceptance is the smallest. The shorter bunch length also contributed to increasing the integrated luminosity.

Optically Pumped Polarized H^- source (OPPIS) – A. Zelenski

Commissioning before/during Run-13

- First year with new OPPIS, reliable operation
- Maintenance time is significantly reduced
- The source intensity is about 5-10 mA (10x more than old source). Strong space-charge limits transport through RFQ and Linac, losses can be reduced.

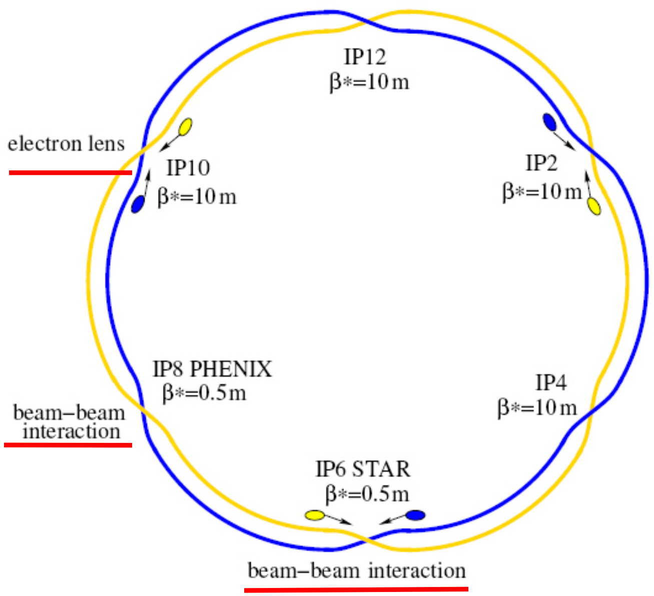
Performance increase to date

- Maximum Booster intensity: **2x higher than Run-12**
- Polarization: 83%, **3-4% higher than Run-12** (at nominal intensity 5×10^{11})

Expect further intensity and polarization increases

- Will be primarily used to increase brightness
- Polarization at store can be reduced by accelerating smaller beams

Electron lenses – partial head-on beam-beam compensation

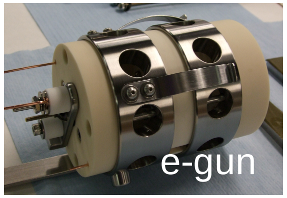


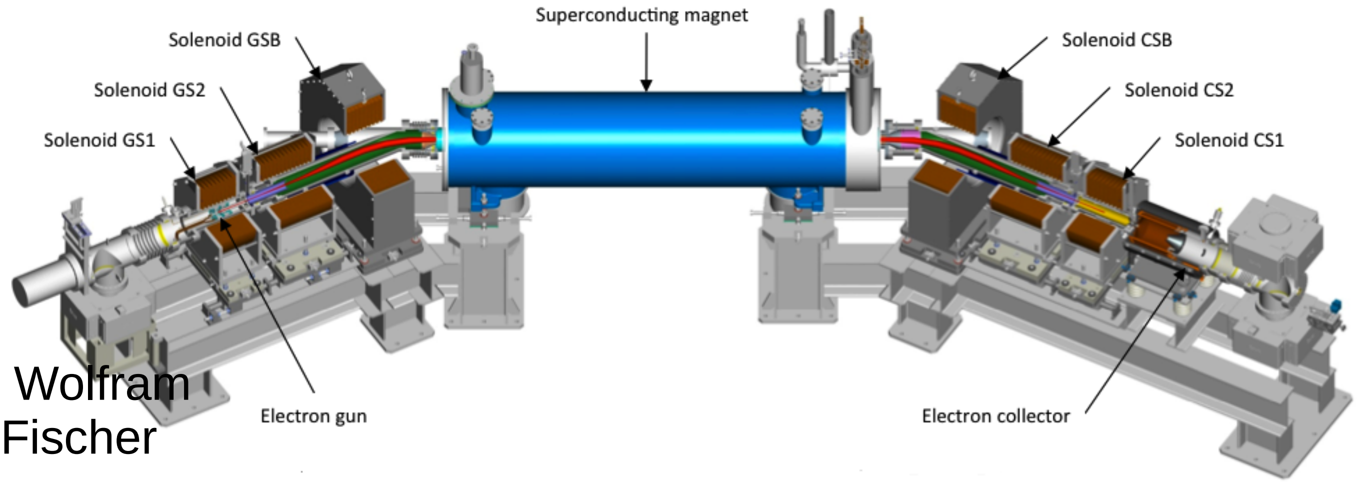
Basic idea:

2 beam-beam collisions with **positively** charged beam
Add collision with a **negatively** charged beam – with matched intensity and same amplitude dependence

Compensation of nonlinear effects:

e-beam current and shape
=> reduces tune spread
$\Delta\psi_{x,y} = k\pi$ between p-p and p-e collision
=> reduces resonance driving terms





Wolfram
Fischer

e-lens Lattice Design

- In order for e-lens to operate correctly there needs to be proper phase advance between IP and e-lens compensation.
- To achieve this phase advance new phase shifter shunt power supplies were implemented and a new lattice designed at new working point
  - Fundamentally different approach to designing and controlling our lattice and on-line model.
  - Also the introduction of the phase shifters had a large impact on the intrinsic spin resonance of the lattice for both good and ill. So this needed to be accounted for in the lattice design.

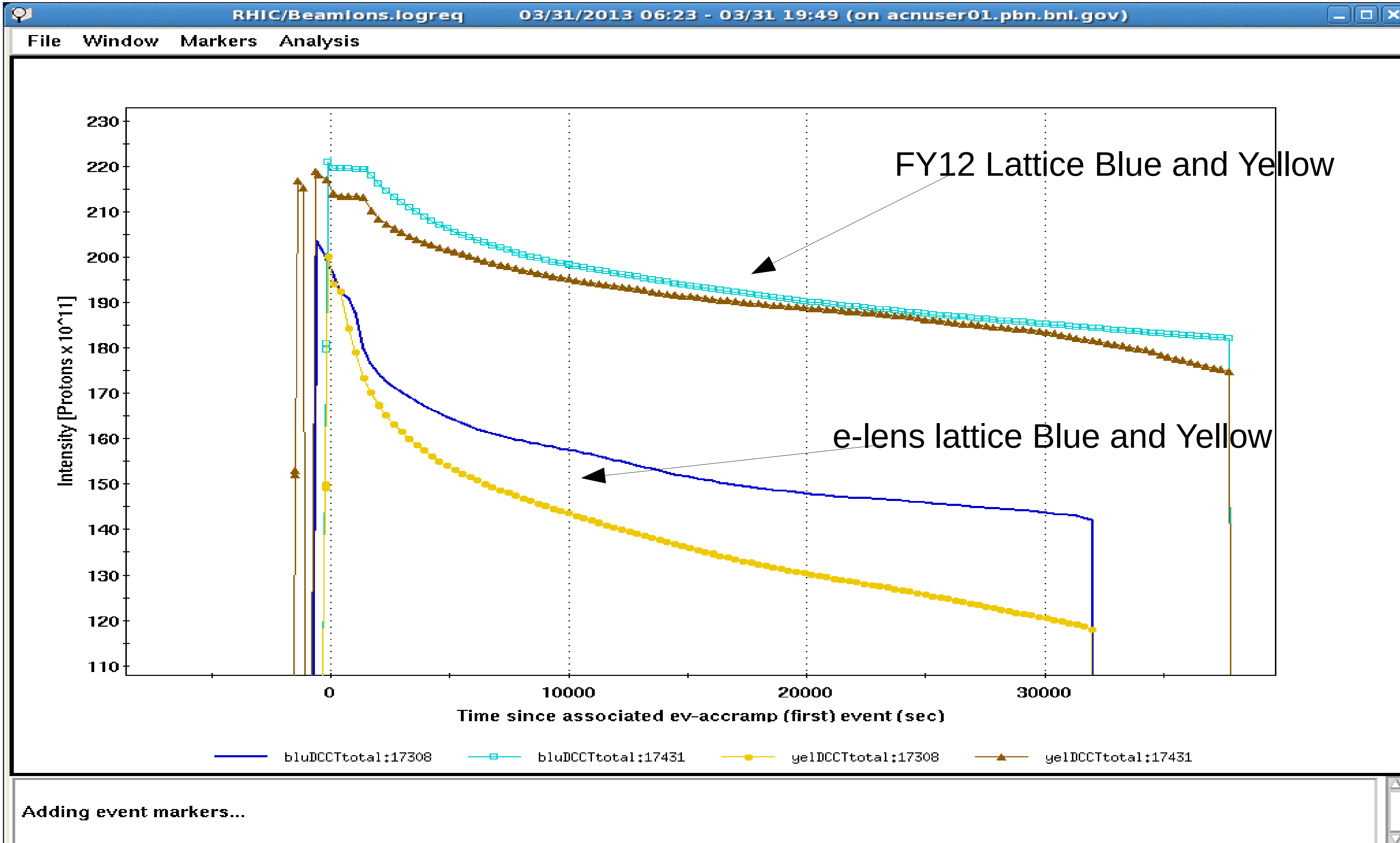
Reduced Resonances by 10 to 14%

Spin Resonance	Blue (new-old)	Yellow (new-old)
231+NU	-0.0387	-0.0415
411-NU	-0.06134	-0.0655
393+NU	-0.05347	-0.0347

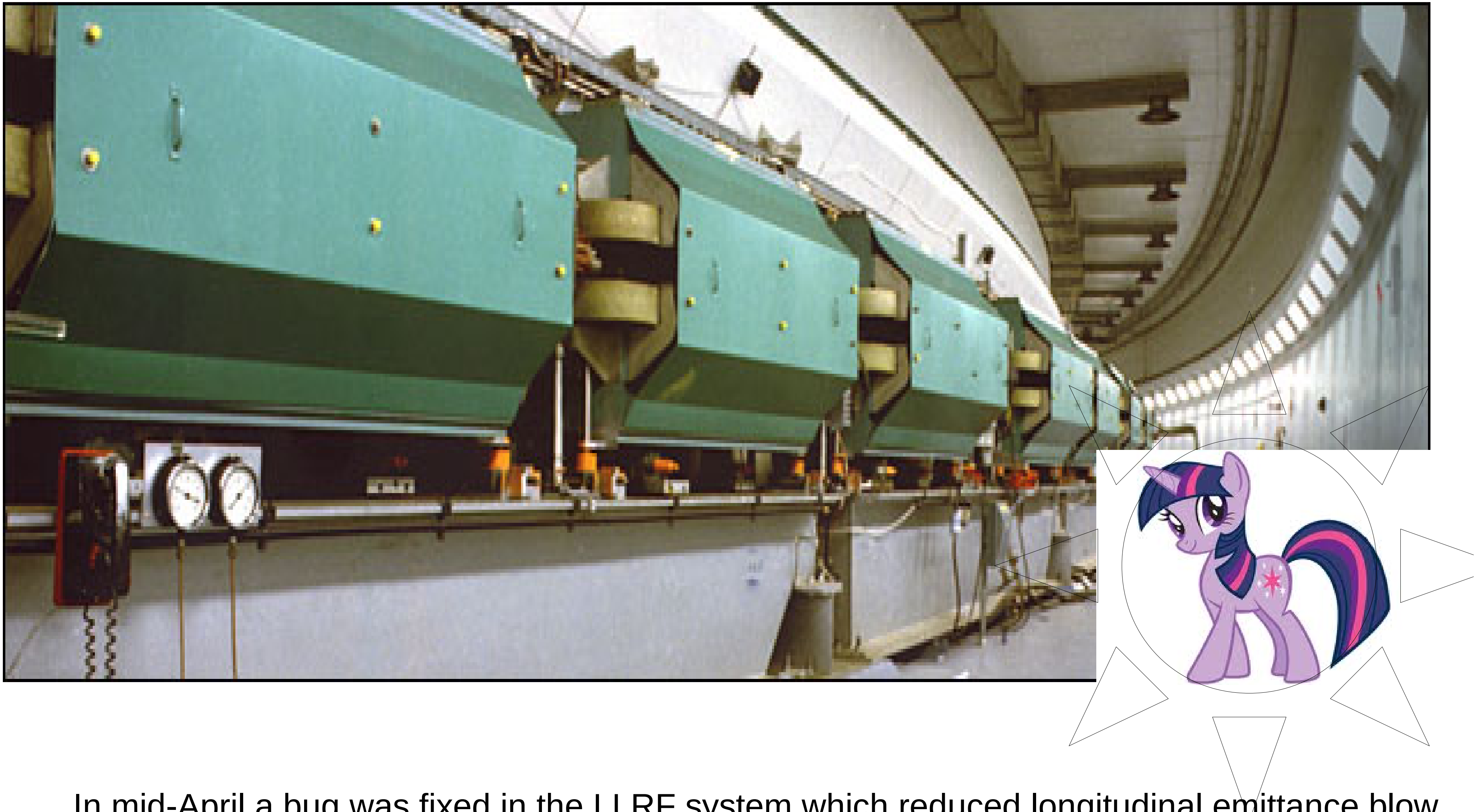
Operations with e-lens lattice

- Initial ramp up to Physics went well
  - Feedback systems with new lattice, Source, RF systems
  - Reduction of aperture at STAR exposed an offset of 5mm at STAR:
    This would cause much trouble later on.
- However Polarization at Collision remained < 50% and we struggled with beam lifetime issues at injection, store and losses on the ramp.
  - It appeared that the resonance driving terms associated with the 2/3rd's tune were much larger than the FY12 lattice. This was particularly so for Yellow.
  - We knew reported emittances at injection were larger than in FY12
    - In fact several weeks into the run we considered changing back to FY12 Optics for but postponed it since we wanted time to see if emittance problem could be fixed.
    - However it wasn't clear if this was a function of our new optics in RHIC, new IPM systems, injection matching, or up stream in AGS or Booster. AGS IPM seemed not to report a significantly larger transverse emittance.
  - After efforts to remedy things at injection didn't payoff we reverted back to the run 12 Optics in early April (5th)
    - While there was a dramatic improvement in lifetime at injection, Store and losses on the ramp, polarization still was low and emittances still large.

Comparing maximum intensity e-lens lattice with FY12 Lattice



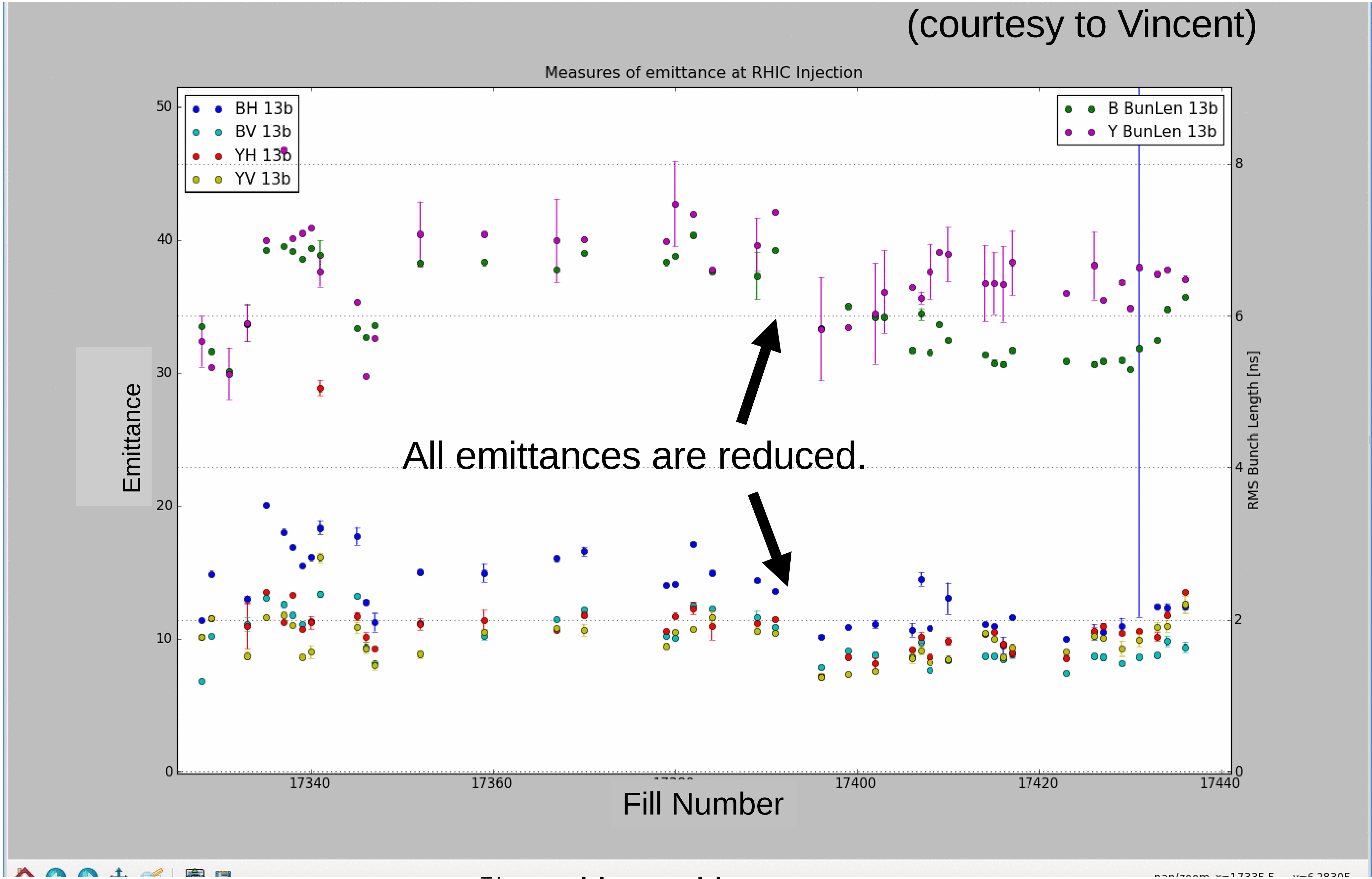
Then Magic Happened!



In mid-April a bug was fixed in the LLRF system which reduced longitudinal emittance blow up in The AGS at transition and RF matching at AGS injection was fixed. The result for the injected transverse emittance were immediate.

RHIC Injection Emit. Changed in 17392 (4/16)

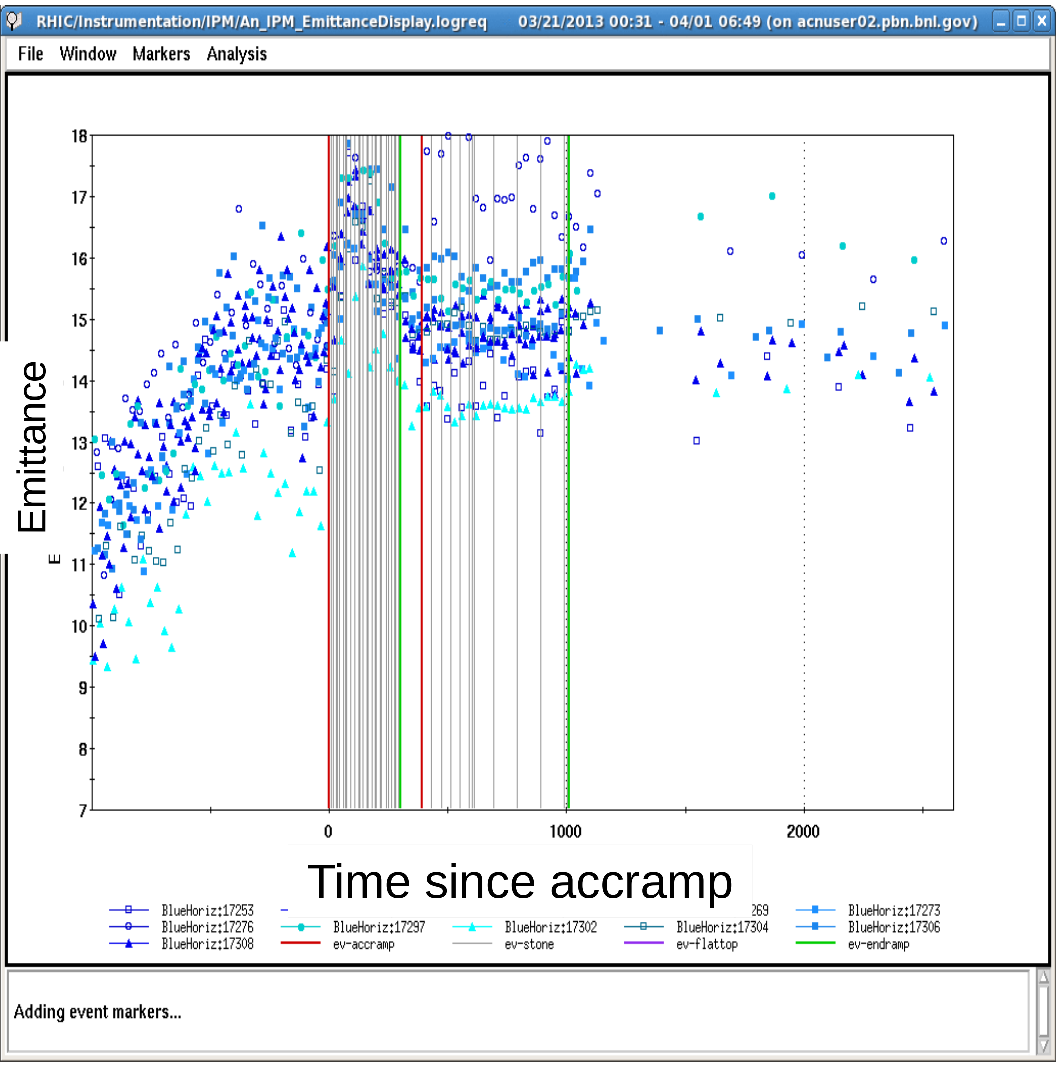
(courtesy to Vincent)



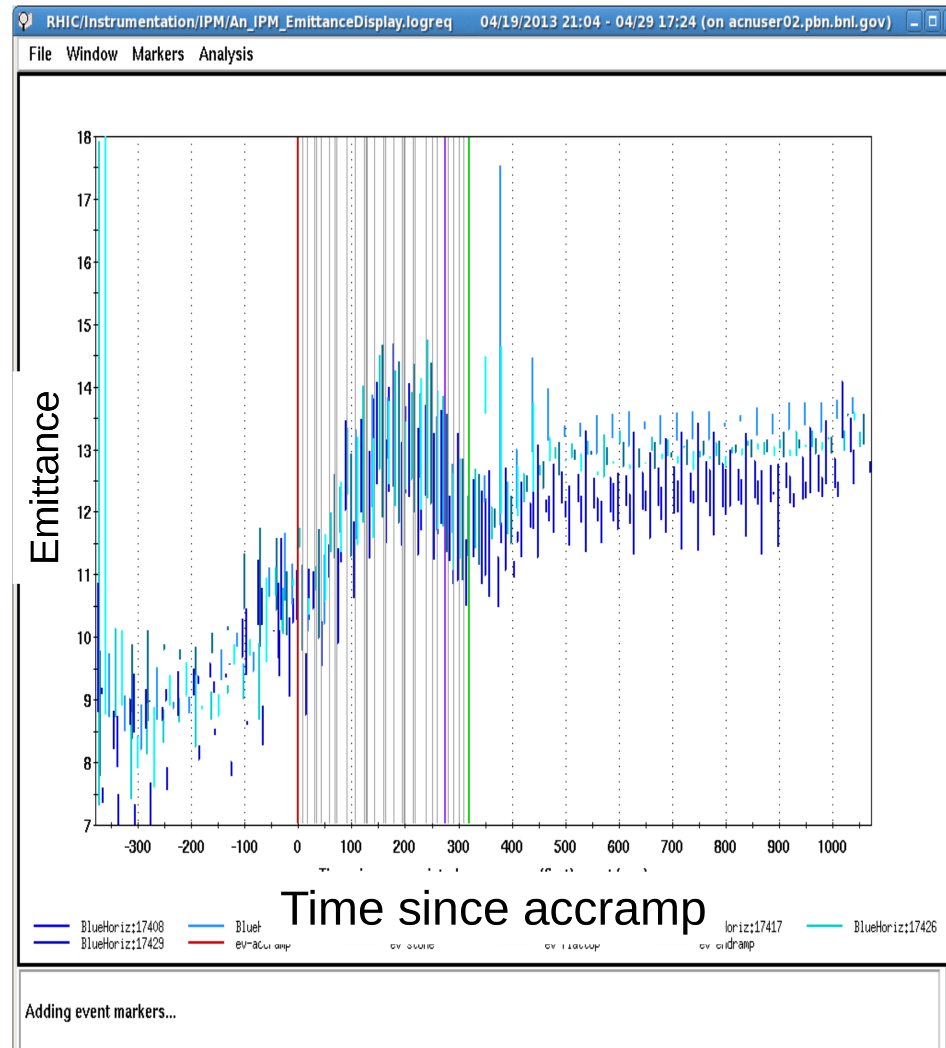
However we still had growth in RHIC

- Backed off on the intensity: Studied the emittance blow-up threshold
  - 2.2e11 for Blue (beam-beam)
  - 2.0e11 for Yellow (longitudinal stability)
- Fixed tunes during the final fill for each ring.
- Changed order of Fills Yellow first Blue second since blue seemed to have larger blow up at injection energy
- Removed CNI polarization measurements at injection and before rotator ramp
- Changed the location of the re-bucketing event to occur at the end of the rotator ramp.

Improvement in Horizontal Emittance



Horizontal emittance through energy ramp before AGS LLRF fix

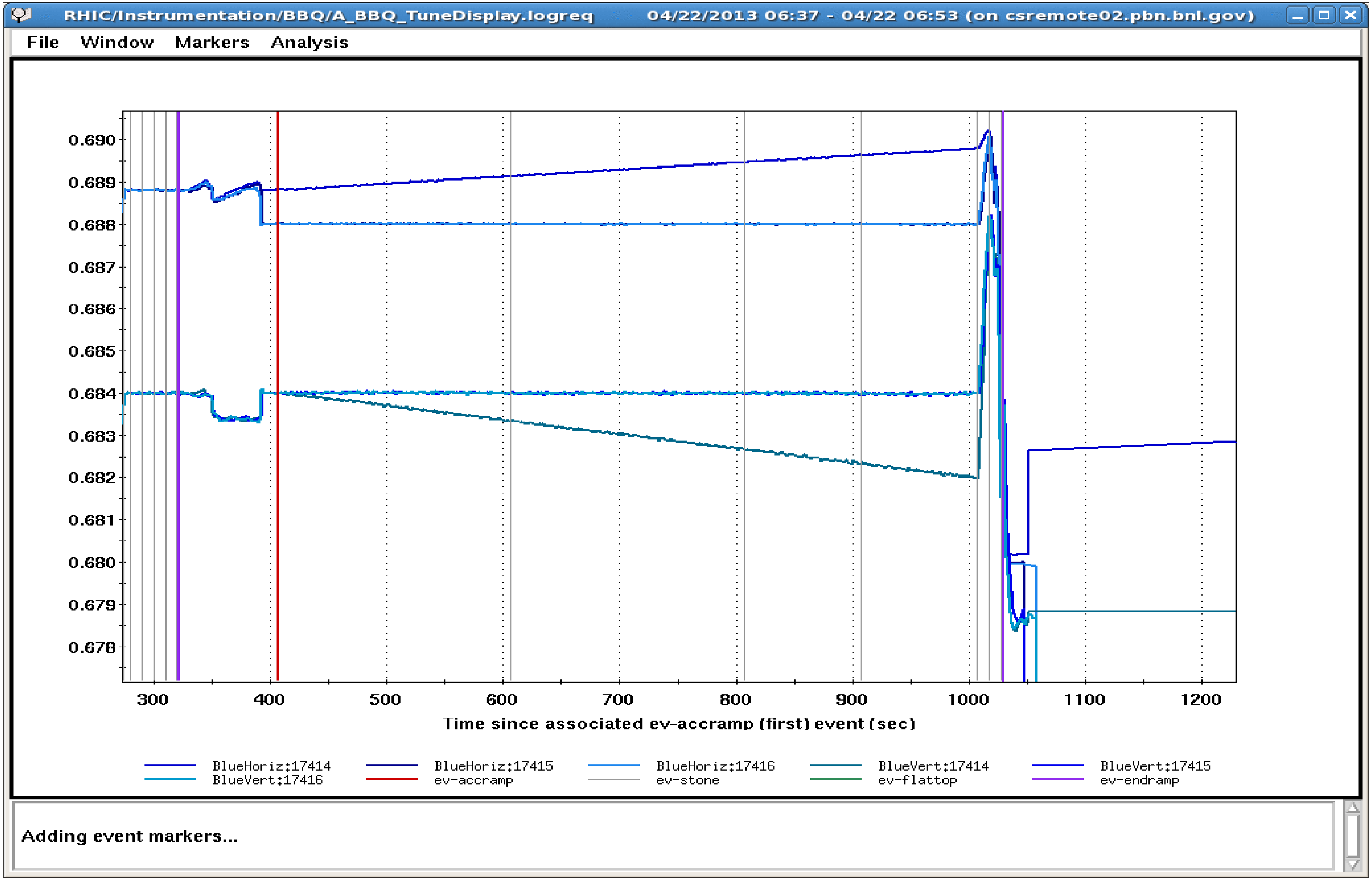


Horizontal emittance through energy ramp After AGS LLRF fix

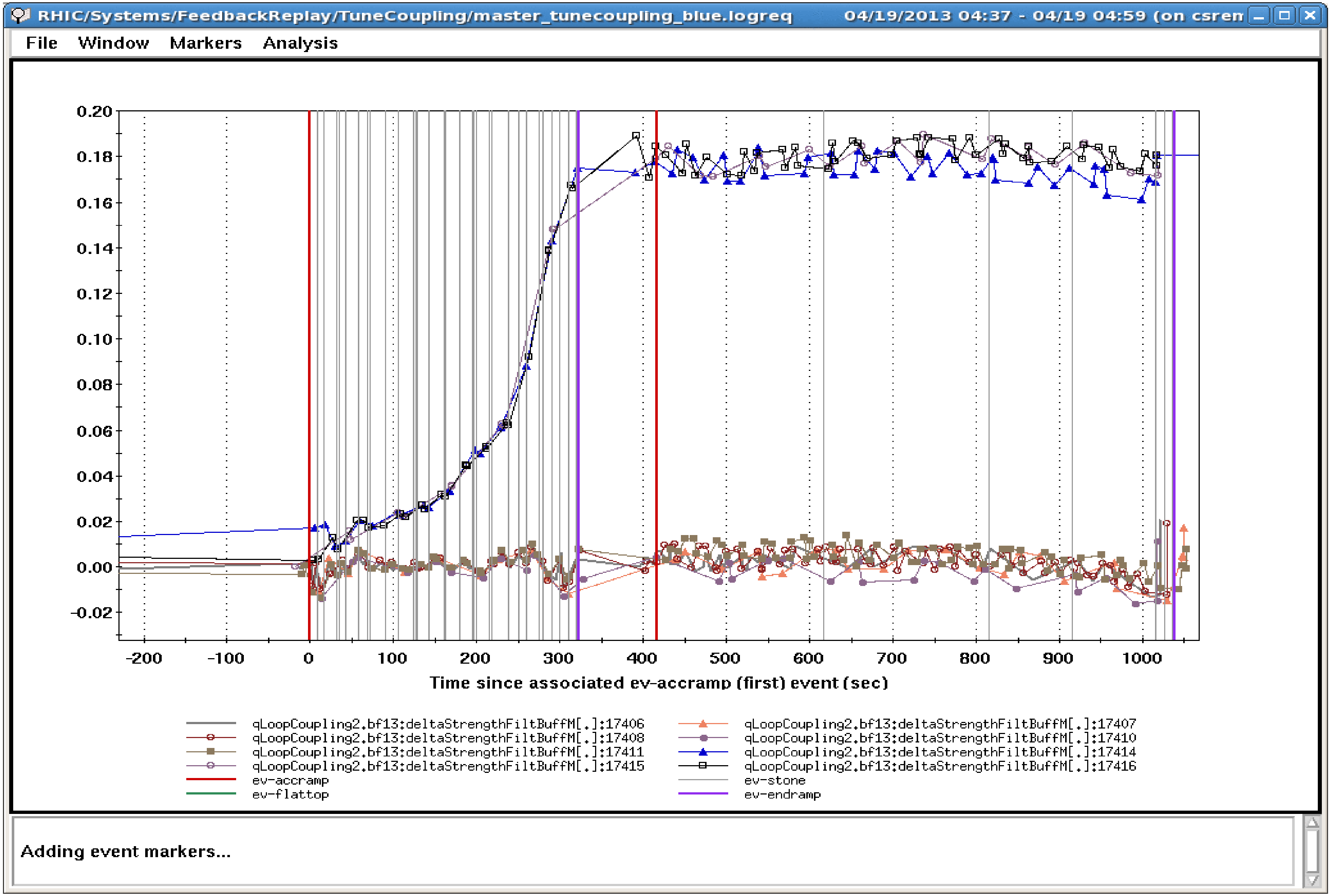
Other Sources of Polarization Losses

- While the impact of emittance reduction was fairly singular in raising our polarization numbers, there were other factors which also had a large effect. In particular Blue achieved Jet values above 55% only after changes to coupling and tunes on rotator ramp.
  - Impact of Coupling? Or Tune on the rotator ramp?
    - For fill 17414 change in skew quadrupole power supply led to a large change in coupling feedback circuits.
    - Also during fill 17415 tunes were flatten out on the rotator ramp.
      - Only two significance differences which preceded rise in Blue Jet numbers. To date we haven't determined the primary driver which lead to 60% Jet numbers seen in fill 17416 and high 50's seen there after for 16 fills. Orbits and emittance seemed not to be a factor here.

Tune Changes on Ramp



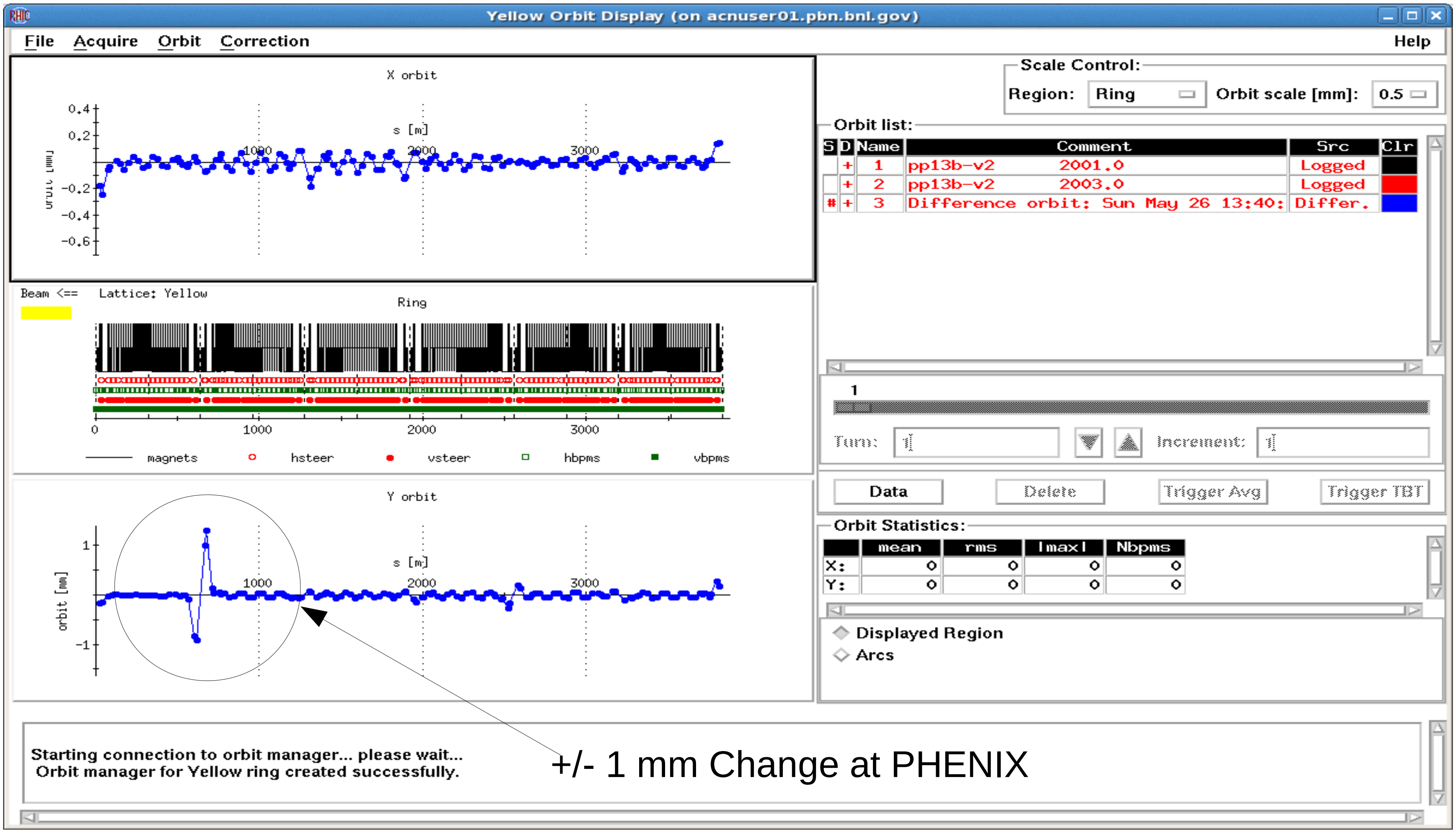
Change in Coupling Circuit



Impact of Orbit Offset and Variation at Rotators

- Orbit offset through rotators
  - Offset by 5 mm at STAR IP caused as much as a 0.025 spin tune shift. The slewing of the spin tune during the rotator ramp probably drove a significant source of depolarization. We are currently still studying this mechanism.
  - Made spin tune particularly sensitive to orbit fluctuations around the Collision IP's which were significant.
- Store to Store orbit variation at rotators:
  - Introduced significant transverse spin component at IP's
    - On several occasions angles had to be manually removed
  - Controlling of the collision orbit was particularly challenging:
    - Orbit would move as much at 2 mm from store to store. This would effect tunes at collision which in-turn also effected emittance blow-up due to beam-beam collisions.

Example of Orbit movement at IP8



Change in Orbit in Yellow between fill 17554 and 17555 which saw jet jump from 0.49 to 0.65

Retrospective: E-lens lattice performance

- From the point of view of beam lifetime and transmission on the ramp:
  - e-lens lattices performed worse than FY12 standard lattice. (10 years to perfect FY12 lattice)
- On the question of polarization:
  - Blue e-lens lattice out-performed the FY12 lattice
  - Yellow FY12 lattice out performed the Yellow e-lens lattice.

Lattice	Average Jet Pol. Before AGS emittance fix (for low error fills <5%)
Blue e-lens	48%
Blue FY12	43%
Yellow e-lens	44%
Yellow FY12	53%

Conclusion

While there were significant challenges during this run much was achieved to push our future capabilities.

- During the second part of the run we reached record luminosities and intensities. This exposed the intensity limits driven by beam-beam effects hence our need for e-lens beam-beam compensation and the e-lens lattice
  - We also saw that it was possible to achieve high Yellow/Blue polarizations with 57.0+/- 0.9% averaged over 16 consecutive fills.
- The first part of the run with the e-lens lattice put us well on the path to developing the technology to overcome the beam-beam limits for RHIC machine.
  - Viable solution for Blue and a path for solution in Yellow.